# An Approach for Discovering Space by the Blind using an Ontology-based Map and Data from Existing Open Maps

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Nowadays, navigation with efficient quality to an unknown place is often performed by everyone. To go forward with this, we usually reach for one of the Internet maps, enter data about the scheduled trip and search for a new route. The visually impaired individuals VI have an even greater need to take advantage of this activity because, while walking independently, they have to find their destination and follow the previously developed route avoiding dangerous places without loosing a proper way. However, despite many publicly available online mapping services, they have great difficulties with this issue. For this reason, the journey becomes much stressful and unsafe for them. To enable this detailed exploration, we propose a method that assigns a new route, describes it with the ontological object map and assigns 3-D binaural sound patterns to them. For this purpose, we use dedicated domain ontology. Apart from the attributes such as coordinates and size, each object has the appropriate physical location and other properties described as semantic data. These conditions are expressed as corresponding relationships, i.e., being a neighbour or being on. Such sets of objects are also described using three-dimensional binaural sound scenes. They are linked to ontology using a special relationship called ”Has-Sound-Scene”. Our concept has been implemented as a simple application that uses ontology, data downloaded from the Open Street Map and audio samples recorded with the binaural sound method. It has a mechanism for determining routes and assigning sound signals to them. The application was tested by two VI users and has received positive opinions.

**Keywords**: Blind traveller, Object map ontology, Sound description of space.

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# 1 Introduction and Background

According to the WHO [1] report, about 45 million blind people are living in the world. Another 269 million are individuals with various visual disturbances. Moreover, "Lancet Global Health" predicts in its report [1] that by 2050 the number of blinds will reach 115 million individuals. While travelling along known routes is generally not a big deal for able-bodied, overcoming unknown routes, especially for the blind, is associated with much stress and the necessity to prepare for them. In such a situation, the sighted being usually gets to know the new route on some website, e.g., Google maps [2] or Open Streed Maps (OSF) [3] or even conducts a more detailed explanation of this, using options such as Street View. In this case, a blind being has a much more difficult task because, from this level, they cannot see crucial and dangerous points on a route, such as crossroads, bus tops, fountains, benches, and others. Fortunately, several GPS-based systems support independent navigation of VI in town space. An example of such a solution can be the Seeing Assistant move [4]. Working on Android and IOS platforms, this application has a pervasive text and audio user interface. It allows many different options, i.e., sets of messages to be spoken during the travel or user profiles such as a pedestrian or public transport profile. The application can also designate a route to a selected point and lead the blind to it. Other dedicated solutions are for smartphones, i.e., DotWalker [5] or Lacalirro [6], with a more straightforward and intuitive UI. Other solution such as GetThere [7] focuses on voice communication with the user and works similarly to voice assistants such as Google Assistant, Alexa or Siri. They talk to the user through spoken messages and the speech recognition mechanism.

However, supporting outdoor navigation is a partially resolved problem. Assisting with independent navigation of VI inside large buildings is a still Bgreate challenge. Some approaches to this problem consist of installing automatically talking points in different cities or building places that users can recognize using an application running on his/her smartphone. An example of such a solution is the TotuPoints system [8] or NavCog [9]. There are also applications based on cameras and laser sensors [10], but such solutions' main disadvantage is relatively high cost because building a separate dedicated device or equipping a white cane or glasses with additional modules [11,12] is not a chip solution. Moreover, the accuracy of data stored in systems such as Open Street Map [3] is often not high enough to ensure adequate obstacle avoidance and route leading. Unlike the sighted, VI needs another very crucial information during his/her travel, such as the location of entrances to shops, the mutual position of the lawn about the Pavement and roadway, characteristic advertising poles, passing fences or even the type of material from which it is made.

An ontology approach seems to be a good choice for solving this problem. One of such solutions is the ontology and IndoorGML language mentioned in [13], where the authors propose an ontological description for the space inside the building, but without implementation in a working application. We also propose the ontological approach described in our previous papers [14], extending it with a prototype implementation that we plan to develop and improve. In short, in this paper, we propose a method that practically consists of setting routes based on data from open maps, supplementing them with additional relevant information, and playing adequately assigned sounds to each object located on the route. These can be prominent and recognizable sounds to everyone, such as the sound of a fountain or a tram turning into a depot, but not only. They can also be sounds specific to a given place, such as cars driving through a hole in the road on the left side of the user or a creaking door to a local shop on the right side. Thanks to this solution, in addition to standard verbal navigation, informing a VI whether or not he is moving in the right direction on a designated route, it will also be possible to become familiar with the characteristic sounds associated with a given route. A blind being can create a good imagination snapshot, a fingerprint of a given place in his mind by listening to these sounds.

Objects on the route and the routes themselves are saved in Object map ontology to enable this feature. This ontology allows for describing the various parameters of these objects and relations between them. Examples of these relations can be: a pavement is a neighbour of a road or bus stop is located on the Pavement. Some of the crucial attributes of such objects are various types of sounds recorded using a binaural technique or generating with the HRTF function [15]. It allows for automatic mapping of routes in the map through objects adjacent to each other, e.g., pavement1 is the neighbour of a pedestrian crossing_1, and a pedestrian crossing_1 is a neighbour of pavement_2. Walking through all objects of a given route, we can play all the sounds associated with subsequent objects. In this way, together with text descriptions of objects, it gives an audio 3-dimensional explanation of the route for the blind individual. Due to this, he can listen to this route before actually embarking on the real town space.

The idea of determining such routes based on data from Open Street Map, assigning sounds to them, and playing them was implemented in the form of a simple prototype application. It was tested by one blind and one visually impaired user. A concept for its implementation and further development met with a positive response. The following sections will present how ontology is constructed and how an application works in practice. Then we will summarise our work and give perspectives for its future development.

## 2 Semantic Information About Objects and Routes

Explaining the environment where the VI is walking requires a detailed description of the crucial objects. To increase this explanation's adequateness and describe the entire routes in a better manner, the user moves, the objects should be connected by various relations. This semantic explanation of the space can be done with a specially developed domain ontology, which defines the city's elements and relationships that are important from the perspective of the blind individual.

Generally speaking, the proposed ontology currently contains 58 classes that can define any part of the city. The structure of classes is hierarchical, e.g., the class Infrastructure for Pedestrians contains classes such as Pavement, Lift, and Pedestrian Crossing. Other elements Of the City Architecture classes are Bus Stop or Trash Can. Users can meet real objects in the city space as individuals. In the ontology, they are represented as objects of mentioned classes. So, the user can take city points from Open Streed Map System [7], and after completion, he can convert them to individuals and then save them in the ontology. Except for individuals taken straight from the existing map system, others inform the blind user about different features accessible for him during his movement. An example of this can be trafficLightArmiiKrajowej3Maja1 type of (class) TrafficLight). It informs the user about the possibility of a safe street crossing. Other components are OWL data properties. They define the data types assigned to the domain (in this case, the OWL classes). For example, the Address class has data properties such as address_country_name (xsd: string), address_building_number (xsd: integer), etc. Other elements of the ontology are OWL object properties. There are binary relations established between two OWL things on OWL individuals. The relevant relations such as neighbourhood, location, and others have also been defined to provide a better and smarter description of an environment in the ontology map. OWL annotations are also used in ontology. They are used to describe city objects or obstacles, which a blind user can recognize to create the audial snapshot of a real-world fragment in his mind.

Some of these elements are classes. They define types of objects of a city's infrastructure such as Pavement, Pedestrian Crossing, Stair, Lift and others. They may be objects such as traffic lights, road signs, a bollard or an advertising column and even a car park cutting into the Pavement. Some classes describe locations, i.e., their destinations labelled by post address or GPS coordinates. Other classes define locations that may be a destination in the form of a building, which has a door to be entered (e. g., bank, clinic, restaurant, school, shop). There are also classes providing handy information essential for the safety of a blind user.

However, we should remember that classes describe city elements as properly defined abstracts. They do not define the specific objects but describe their properties and purpose sets. For defining specific objects on the map, the individuals are used. In our case, they represent all the places or physical elements in the city whose types were previously defined by classes. Examples of individuals can be pavementPilsudskiego01 (the class of Pavement) – a first section of the Pavement on the left side of Pilsudskiego street; or pedestrianCrossingPilsudskiego01 (the class of PedestrianCrossing) – the first pedestrian crossing through the Pilsudskiego street at the intersection of Pilsudskiego and Wojskowa streets. When defining the city objects, we must pay special attention to those that may be an obstacle for a blind user. Individuals representing obstacles are: trashCanPilsudskiego01 (the class of TrashCan) – a trash can locate on the edge of the Pavement on the street side or busStop01SiedlcePilsudskiego01 (the class of BusStop) – a bus shed located in Siedlce city in the middle of the Pavement, it can be walked around from both sides. Some other objects (individuals) may be recognized by listening to their specific sounds. Such kind of object can be, for example - trafficLightPilsudskiegoWojskowa1 (class of TrafficLight) that carry information about the possibility of a safe crossing of the street.

The ontology also defines two types of properties: data and object properties. The data properties define the types of data assigned to the domain. For example, the Address class has defined data properties such as address_country_name as a string, address_building_number as an integer. In turn, data properties are binary relations between two individuals in ontology, and they are used to define any relationship between them. In order to ensure an accurate description of the natural environment, appropriate relations have been defined, for example:

- *appliesToPedestrian*. This property is used to determine the membership city object to another object. For example, only one object of the class *TrafficLight* can apply to only one class, *PedestrianCrossing*.
- *hasDirectNeighbor*. This significant symmetric relationship means that two objects are adjacent neighbours to each other. e. g. when the Pilsudskiego pavement (individual) is in this relation to Armii Krajowej pavement (individual), we can infer that Armii Krajowej pavement must also be in relation with Pilsudskiego pavement via the *hasDirectNeighbor* property. It is worth adding that this property allows us to determine the next sequenced elements.
- *isLocatedOn*. This property is used to express that something is located on the route of a VI. For example, a trash bin is located on the Pavement and may be an obstacle for the user.
- *recordedInTheLocation*. This property is used to assign a sound to a specific location. For example, the sound can represent a signal that the user can listen to while crossing the street.

Any object in the ontology representing a point on the map can be assigned a sound. These sounds can make up binaural three-dimensional sound scenes that describe different routes that blind users can meet. They can be recorded from the real world or generated automatically. Moreover, a standard OWL ontology syntax for text annotations is used to provide additional information to the user, such as descriptions, safety warnings, or more detailed explanations of a given place. These labels can be read automatically by a speech synthesizer.

The standard commonly known Ontology Web Language OWL [16] was chosen as a language for expressing our ontology. The part of the OWL ontology that represents the class hierarchy and several individuals is shown in Figure 1.

## 3 The Method and Its Implementation

To describe the space for the VI user, we use a method that works in the following steps:

- In the first step, as input to the application, we take the ontology with the appropriate classes and properties (see the previous section). To ensure faster working, we save them in the relational database.

- In the second step, natural objects data are retrieved from the open OSF map system and combined with the ontology. Thanks to this, ontology with a set of individuals describing physical city objects is created.
- In the third step, the object data are manually completed with the properties relevant to the VI specific needs. Moreover, we add sound schemes to some objects. The sound patterns are pre-recorded using binaural technique or created with the HRTF function [15]. These are the so-called binaural Sound scenes.

With such a knowledge base describing the environment, we can determine routes and present them in audio and a simple visual scheme. We can also implement a mechanism of virtual travelling.

A simple desktop application has been implemented as a practical implementation of our method described above. It uses the ontology and data concerning the existing points of interest taken from the Open Street Map system [3]. The prototype application consists of 3 main modules:

- The sound map creation module. Its task is to retrieve data from the ontology, retrieve actual point data from OSF, complete this and combine it with binaural sounds.
- The free travel module. Its task is to enable the user to play audio routes and navigate them in the application.
- The routing travel module. It takes data from the map creation module, calculates routes and passes them to the virtual travel module.

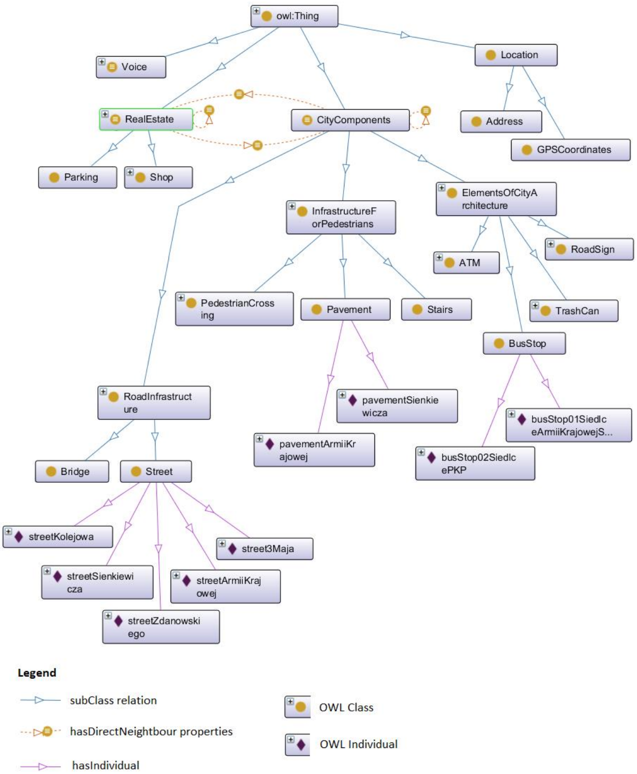


**Fig. 1.** Sample ontology

Each module is integrated with the Open Street Map engine and uses the OWL objects repository. The primary application architecture is presented in Figure. 2.

An OWL Map Creation module is a graphical interface to the OWL repository. It consists of a simple form that allows the user to expand the map with new points/objects. The form contains fields for entering the name, description, class, and geographical position in GPS format. A vital feature of this module is adding sounds to a new point. Thanks to integrating this module with the Open Street Map, by adding a new point to the map, the user can faster find this point by a given phrase. The results of this search appear in the form's drop-down list. After selecting an item from this list, the form fields for the new point coordinates are automatically completed. The data from the form is finally persisted in the OWL repository.

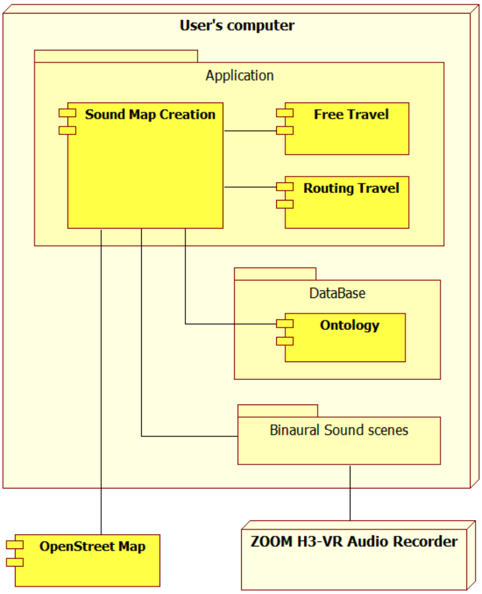


**Fig. 2.** Basic application architecture

A Free Travel module allows the user to move freely on the sound map within a certain radius from a given starting point. Due to efficiency, we need the radius to load the points from the ontology file into memory. The starting point can be specified manually (by entering GPS coordinates) or searched using the Open Street Map engine. Then the user starts his virtual journey from the mentioned starting point. Navigating around the map can be performed with eight directional keys that the user can use with the mouse or numeric keypad. While the user is moving, the system permanently finds points in the ontology within a given (e.g., 20 m) distance from him. These points are presented graphically in a list. After selecting an item from the list, the user can listen to the sounds related to the given point.

The Routing Travel module allows the user to create an audio route from the start point to the endpoint, near which the system searches for OWL points containing audio recordings. The route mapping takes place in two steps. We calculate the route using the Open Street Map service in the first step. The obtained result is a list of points (p_1, p_2, ..., p_n). Then, for each segment (pi, pi+1), points located in the distance less than a predefined value (e.g., 20 meters) are searched. Because points are taken from the OWL map, the final result is the list of the OWL points. Then all these points are presented in GUI. Every item on the list can be selected, and their sounds can be played. In this way, the user gets to know the route by listening to sounds accompanied to all objects sequentially. Figure 3 shows a screenshot with a GUI of a routing travel module of the application.

## 4 Conclusions

In this paper, we have presented a method of audio description of the environment to assist the independent navigation of the blind. This description is built as a specially created domain ontology in which individuals, classes, and relations define and describe objects from the urban environment. What is very important for a future blind user, some objects from this ontology are associated with sounds and text labels that create a virtual sound reality that acoustically describes the space. These sounds can be recorded using a binaural technique or created using acoustic filters such as the HRTF function [15]. Thanks to this, a blind user listening to these sounds has the impression that they come to him from different directions. It is similar to the actual environment, where he can listen to various street noises during his travel.

We have implemented our method as an example prototype application. It allows the user to determine the route based on the data downloaded from Open Street Map, assign appropriate sounds to the points of this route, and then play them. The two blind users have tested the application, and their idea met with positive feedback. However, more research is needed to adjust our method better and develop it. The application is still in progress, and we plan to build more complex systems supporting independent navigation and learning spatial orientation of blind individuals in the future. One of such possibilities will be a mobile application supporting the navigation of the blind in the city space.

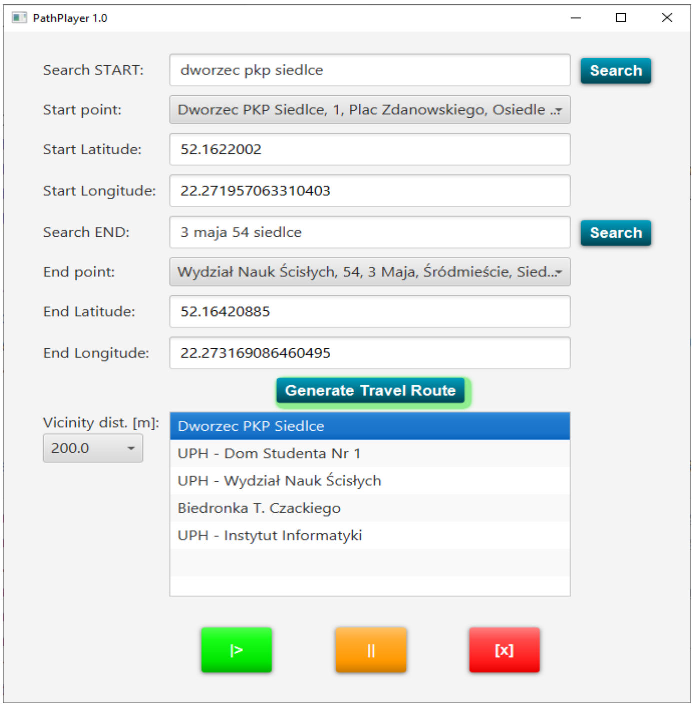


**Fig. 3.** Routing Travel module GUI

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